Condition monitoring for a large fleet of wind turbines

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Introduction

Uniper Technologies Condition Monitoring, prior to splitting from E.ON, had contributed to the adoption of vibration analysis within E.ON Climate and Renewables (EC&R), and supported the central team to implement a retrofit project on over 1,000 wind turbines.

Our long experience in providing monitoring services to both conventional and renewable generation led us to being the partner to carry out monitoring using the newly installed systems.

This was not without challenges, as it entailed scaling up from daily monitoring of around 130 wind turbines, to approximately 1,300. In addition extra work to monitor pre-installed systems represents takes us to over 1,500 in total.

We drew on our experience of scaling up our condition monitoring services for main turbine shaft vibration monitoring, which began when the first remotely accessible vibration monitoring systems were introduced, and has now grown to well over 100 shaftlines. Whilst the technical details for monitoring wind turbines are somewhat different, the principles of condition monitoring can be distilled to a few key areas that are vital to the success of a service. The technical details for wind turbines are akin to typical auxiliary plant found on power stations, so we were also familiar with the key requirements in this respect.

Adapting to wind turbines

This put us in the perfect position to support E.ON’s wind turbine fleet as it made the transition from boutique to industrial during the mid-2000s. We provided a detailed technical specification as to what we would expect from a vibration monitoring system to allow effective capture of the data required to monitor a wind turbine. The equipment on a wind turbine is typically of a size and design that would have historically been monitored using hand held equipment on a route-based regime; i.e. rolling element bearings, small electrical machines and gearboxes. However, the difficult access means that the installation of permanent monitoring equipment becomes a more cost-effective solution. Furthermore the wind is generally not constant, and turbines run at varying speeds and loads. So it becomes necessary to add a trigger to cause the monitoring system to capture data under specific conditions and a further logic condition which will reject data if the variation of conditions within the sample is too great. This can only be done when a permanently installed system is used.
The specification we developed successfully addresses these challenges, in addition to retaining the generally accepted best practice requirements for vibration monitoring of this type of plant (i.e. FFT analysis, demodulation, filtering, order tracking...); we also carried out market testing to ensure such systems were in existence. Our colleagues within EC&R then ran the major project for the installation of technically compliant systems across a large portion of the E.ON wind turbine fleet.

Strategy of the monitoring service

Having been partners to EC&R throughout the process, and having monitored suitably-equipped UK wind turbines since 2007, we took on the role of expanding our monitoring service to cover the turbines with these newly installed systems in the E.ON fleet in Europe and North America. Following on from this we were asked to take on further turbines which had OEM-installed systems as these came out of warranty. In addition at a small number of sites we have also implemented a SCADA monitoring service, again developed from our experience with conventional plant, using an algorithm called SpheriCAL™ which we developed in house.

When devising a service offering it is worthwhile to start with the question of why we are doing it. In the case of a condition monitoring service this is generally summarised as:

- To provide early warning of developing faults;
- allow better maintenance planning;
- allow the customer (with our support) to challenge the OEM;
- help avoid unplanned unavailability;
- support investigations to understand failures;
- or in other words to save our customers money.

This can only happen if the monitoring follows a consistent strategy and has clear lines of communication between those carrying out the monitoring and those carrying out the maintenance.

Our strategy is based on ISO17359 “Condition monitoring and diagnostics of machines – General guidelines” which sets out in some detail how to go through the process of selecting appropriate measurement techniques and intervals for a variety of machines. In the case of wind turbine monitoring there is less variation from machine to machine, although it is still necessary to be aware of the foibles of different designs.

There are two strands to the strategy. The first is the set-up of the monitoring involving equipment audit, failure mode analysis and selection of measurements. The second stage is the continuous monitoring process. These two strands are illustrated in Figure 1. The equipment audit and selection of potential measurements can be revisited in the event of new knowledge, and this may include adjustments to the way in which measurements are made. A good example of this is the tower natural frequency monitoring that we introduced for two offshore sites vulnerable to scour. Through a modification to the sampling time we were able to attain measurements at sufficient resolution to detect changes to the tower natural frequency that would be indicative of a significant change to the strength of the foundation. This allowed better planning of maintenance, opened up more cost effective maintenance options and enhanced availability.

The continuing monitoring cycle can be considered as a process which transforms data into information and brings together strands of information to create knowledge which can be acted upon. In this context:

- “data” is the state of the machine, e.g. operating speed, load, vibration, temperatures, flows, pressures and so forth;
- “information” is the trends of appropriate characteristics from the data analysing the process, and having monitored this is generally 

More data and information are also gathered in the feedback from the maintenance to create knowledge which improves future prognostic estimates. This is vital in allowing the monitoring service to mature and drive continuous improvement. Whilst many people are keen to gather all the data available, it is actually knowledge which creates value for an organisation; so our approach has been to leave the data in the systems which contain the relevant analysis tools, but to make the knowledge widely available to all those who need it. Engineers from E.ON Climate and Renewables can view any alert raised by our team, and the entire history of the symptoms through to the findings at repair, in order to assist with decision making.

There are a number of advantages to centralising the monitoring function, especially when considering the generation of knowledge. Since a central team is looking at a much greater number of turbines they have the opportunity to see a much larger number of faults. This leads to more rapid acquisition of knowledge. In turn all the sites that are covered benefit from this knowledge in the event of a similar fault. Also the central team can concentrate purely on the monitoring, whereas local technicians would be called onto other duties, and would not have the time available to specialise.

Strategy into action

So the process we have adopted for the monitoring of wind turbines can be outlined as follows:

The key failure modes are identified. The indications for each of these failure modes are considered, and the monitoring systems are set to capture data appropriately to identify these failure modes. It should be noted that often multiple failure modes can affect the same indication, so it is not straightforward to programmatically link indications to failure modes.

Baseline levels are generated from the first few months of operations. The initial alert and alarm levels are then set relative to these baselines, once it is ascertained that there is no fault indication within the data collected for the baseline. The setting of baselines is actually more complex than might be supposed, particularly if there is variability within the turbine conditions when data is captured.

When an alert or an alarm is generated it is important to learn from the findings:

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was the alert too early (little damage when component changed); too late (consequent damage); or approximately the right timing. We use this to refine alert and alarm levels and to inform the timing of when future alerts should be raised. It is also important to learn from missed failures, and review the data to find out whether there were any extra frequencies or symptoms which appeared prior to the failure that could have detected the problem, and would do so again in future. It is often found that the quoted frequency bands are not quite accurate and require some refinement, in particular in the cases of multiple harmonics, overlapping fault frequencies or multiple sidebands. It is not always possible to fully separate these, but some refinement can be made to improve the results and cut down on false alarms. There is an ongoing process to try to refine alert and alarm levels to reduce false alarms. The nature of condition monitoring requires that alarms be set tightly, leading to far more alarms due to statistical noise than would be tolerated by a control room. However if the number is too great, real indications will be missed, hence it is important to look to continually improve the settings. When findings are reported to site, it is best to provide simple, focussed information. As discussed below, it must be made very easy to provide feedback, as this is of great importance to the monitoring process. Often an issue raised today may not be addressed for several months, so it is worthwhile to provide status updates to track the results, which provides an extra opportunity gain feedback.

Finally it is always worthwhile to keep a note of the savings to justify the investment. Many manufacturers of condition monitoring systems will make outlandish claims as to the amount saved, which causes the entire sector to lose credibility. We aim to be much more conservative in our cost saving estimates. For example, take the common case of a failing generator bearing, as illustrated in Figure 2. Low end estimates for the saving would be around 5 hours lost generation (~ €500), as early detection allows the repair to be scheduled into a low wind period, or during an outage on other equipment. Worst case scenarios involve secondary damage or damage to the shaft or contact between rotating and stationary parts, which may require a generator replacement. For an offshore farm you would then need to add in the cost of crane hire and perhaps several months of lost generation (>€500,000?). This could represent a difference of up to three orders of magnitude in the savings. We would typically claim around €3,000 which represents a 1 in 10 chance of consequential damage, and placing the cost of replacing a generator at €100,000.

The initial setup for ACM based on SpheriCAL® is slightly different, as this is looking for changes from normal behaviour rather than specific threshold values or specific failure modes. For this we need to select groups of parameters we expect to have an inter-relationship, and specify how far we would allow them to drift from their normal value. Once this is complete the monitoring process follows a similar pattern to that for vibration monitoring as regards checking for alarms, relating these to failure modes, alerting site and seeking feedback. We have had several successes using this technique, particularly with regard to bearing temperatures, cooling systems and electrical systems. Figure 3 shows a typical example of a SpheriCAL® finding relating to a failed thermostat.

Maintaining quality with higher workloads

From our existing experiences we knew that the quality of service that can be provided depends upon four key ingredients. These can be summarised as People, Processes, Systems and Communications.

People

The recruitment of good people is perhaps easier for a large organisation such as E.ON/Uniper with significant HR support and access to national and international advertising, but that is not the end of the story. We run a competency assessment scheme to help with resourcing and to address training needs and ensure all staff members are refreshing their skills. For vibration analysis we supplement this with BINDT’s PCN certification scheme to help with resourcing and to address training needs and ensure all staff members are refreshing their skills. We run a competency assessment scheme to help with resourcing and to address training needs and ensure all staff members are refreshing their skills. For vibration analysis we supplement this with BINDT’s PCN certification scheme to help with resourcing and to address training needs and ensure all staff members are refreshing their skills.

Fig. 2. Typical example of the vibration signature due to a generator bearing defect.

Fig. 3. Typical example of a problem picked up using SpheriCAL®. Brown trace is actual data – blue is expected value, with light blue and light green showing dynamic alarm boundaries.
findings are seen by more than one person, accelerating the learning process for new or unusual fault types. In this case the peer review process will often extend out to several other members of the team.

It is an advantage that we are able to operate a relatively large team in order to cover monitoring of both conventional and wind turbine plant. It is necessary that there is sufficient resource not only to cover the daily monitoring requirements (which vary significantly with the weather patterns) but also to cover the administrative tasks such as updating thresholds and responding to feedback as necessary. By recruiting into an existing team we have been able to reduce the administrative burden and have a flexible resource to deliver the required monitoring. There is also the possibility to share tasks around in order to prevent boredom. This is not simply for the well-being of the team members – boredom can be a significant problem when faced with a repetitive task, such as analysing vibration from hundreds of identical turbines. Knowing that you will be doing something different tomorrow provides a reason for doing today’s job well.

**Systems**

There are numerous monitoring systems available on the market place, all of which have advantages and disadvantages. Within our daily monitoring we are checking data from Bachmann, SKF, Gramm and Juhl and B&K. All these systems have their own way of analysing the raw data, setting up alarms and alerts, and trending the information. We decided not to follow the path of integrating into a single system, as we had done with our Tiresias system for steam- and gas-turbine data, for a number of reasons:

- There were sufficient numbers of each wind turbine system such that the overhead of learning the software was not so significant
- Data from rolling element bearings requires the setting up of multiple fault frequencies, so there is not the same level of commonality between wind turbine types (and therefore analysis parameters) as seen on conventional plant.
- The differences between systems in the way that spectral and demodulated data are captured and stored make a single system more difficult to build
- The distributed nature of wind turbine monitoring systems – all are based on a central database talking to distributed hardware – means that speed of data access is much less of an issue than for systems which are purely local, such as those typically used on conventional plant.
- In our strategy we recognise that the knowledge generated needs to be shared, and so we keep that in a unified system. The data underpinning this knowledge does not need to be in a unified system.
Rather than focussing on the data collection methods, we chose to concentrate on the desired outcomes, i.e. that an alarm would be raised when a fault was detected. The set of analysis parameters chosen is based on the turbine design and the fault frequencies associated with the components used in the turbine. We have built add-ons where necessary to extract certain parameters that are connected to specific fault types, and make regular adjustments to prevent too many false alarms from being raised by the systems.

Processes

When dealing with a large number of turbines robust processes are essential. Whilst an ad hoc approach might be sufficient for skilled technicians looking after only a small number of turbines, the scaling up process requires formal procedures to be in place, both for scheduling and for describing the regular tasks.

Firstly there is a requirement for a procedure which outlines the aims of the service and details how this will be achieved. This provides an outline for the daily duties of those nominated for the monitoring, and covers issues such as prioritisation, reporting, peer review, checking for data transfer and checking for site outages.

Secondly, there are sets of guidelines to help make the setting and revising of alert and alarm levels more consistent; in some cases there are specific guidelines for specific systems due to the different alarm frequencies associated with the components used in the turbine. We have built add-ons where necessary to extract certain parameters that are connected to specific fault types, and make regular adjustments to prevent too many false alarms from being raised by the systems.

Communications

Communication is the key to any successful business, and is also a very difficult topic to manage. Our experience tells us that the longer a message is, the less likely it will be read and acted upon. We therefore endeavour to keep messages short and to the point. We have developed a portal based system for storing all the knowledge accrued during condition monitoring activities. The philosophy of this portal is that it is social media for condition monitoring. Figure 4 shows a screenshot of a typical alert.

The alert consists of titling which identifies the plant item, a short description of our finding, a colour coded severity and a short recommendation (which may be purely a request for information). Pictures can be added to illustrate the findings, both by ourselves and by site engineers adding feedback.

The system is deliberately designed to make feedback from sites very easy. Actual messages are sent via e-mail, as everyone will have their e-mail open, whereas they may choose not to open a portal session on the intranet. From the e-mail, feedback can be added simply by clicking the link, typing the feedback and pressing save. All recipients see the feedback which has been added. Since we introduced this portal there has been a huge increase in the amount of feedback we receive, but we are careful to avoid unnecessary communications via this route.

Summary/result

Our results since the start of the fleet-wide monitoring have been interesting. During 2015 we raised over 550 CMS alerts and around 60 ACM alerts. Some of these related to instrumentation or loss of communications, but there were also a significant number of alerts relating to fault conditions which are of tangible or intangible benefit. Our conservative estimate is that savings in excess of € 2 million have resulted from the CMS service, and of over € 1/4 million from ACM, both representing a positive return on investment.

Our efforts to maintain our quality whilst expanding our service have been successful but we strive to continuously improve. To that end, our interpretation of best practice in condition monitoring is:

- Condition Monitoring that is applied is based on what can be detected which is of benefit to the operations and maintenance team.
- Techniques and Frequency that are based on FMEA and reliability
- Central Coordination to enhance diagnostic capabilities
- Data from Condition Monitoring converted into Information, which is analysed to give Knowledge that departments can act on
- Single Knowledge Storage System used by everyone
- Knowledge drives operational and maintenance decisions and Actions (both short and long term) at both a site and a fleet level
- Best Practice is when you are generating positive outcomes from Condition Monitoring and continually improving the processes

References

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